§16. Real Time Control of Probe Beam Trajectory in HIBP System

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Heavy ion beam probe is a very powerful diagnostic tool because it can measure directly the potential in toroidal plasma without any disturbance to plasma. Its spatial/temporal resolution is well enough to study the fluctuation related to turbulence, zonal flow, as well as MHD instability. In recent development of our HIBP system in LHD, the capability of measurement was improved[1-2]. One of improvements is the installation of real time control system of probe beam. This system enables measurements of potential on the condition of large toroidal plasma current.

In the case that the large toroidal current exists in plasma, the probe beam orbit of HIBP is influenced by magnetic field produced by the toroidal current. The shift of beam position on the detector is to the toroidal (horizontal) direction because the poloida magnetic field due to plasma current makes a dominant effect on the probe beam orbit. If the shift of beam position on the detector is larger than the size of detector, the probe beam cannot be detected and the potential measurement is impossible. Detector of probe beam consists of 4 plates, which are aligned in two vertical column and two horizontal rows. On the assumption of current distribution in the beam image on the detector being uniform, the position of beam image can be estimated from detected current by each plate. The toroidal (horizontal) position of beam image on the detector, x, is expressed as $x = (I_R - I_L)/ (I_R + I_L) \times C$. Here, I_R (I_L) is the current detected with the right (left) column of detector plates, and C is the half width of beam image on the detector. We define E as the normalized horizontal position, x/C. When the toroidal current in plasma increases, the value E also increases (or decreases). To suppress the variation of E, the voltage of detector side deflector in the toroidal direction, V_{def} is controlled. The typical time scale of toroidal current variation is 0.1 seconds. We designed the feed back control system of which typical control frequency was 1 kHz taking account of the sufficient margin of control. In this system, a digital signal processor (DSP), C6416, was employed, of which cpu clock frequency is 1 GHz. For the feed back algorism, the proportional-integral (PI) control was applied. The proportional integral derivative (PID) control is more general, however signals are noisy, so the calculation of derivative was difficult and was not used.

The experimental result, in which the real time control was applied, is shown in Fig.1. In this case, the observed position was fixed, so only the voltage of detector side deflector in horizontal direction was varied. In Fig.1 (a), the time evolution of the normalized horizontal position, NRL, and the voltage of detector side sweeper, V_{def}, is shown. NRL was constant and the effect from the toroidal current was suppressed successfully. V_{def} was controlled in real time to compensate the effect from toroidal current. Fig.1 (b) shows the temporal evolution of toroidal plasma current I_p and the sum of probe beam current detected by the detector. In the case of the operation without real time control, the position of probe beam on detector moved in toroidal direction and the sum of detected beam current decreased and disappeared if the toroidal beam current, I_p, exceeded 40 kA. In the case of the operation with real time control, the sufficient level of sum of detected beam current was maintained even when I_p exceeded 100 kA.

In profile measurement mode (sweeping mode), the voltage of injector side deflector is swept by 10 Hz and the incident angle of probe beam is changed in this frequency. The experimental result in this mode, when the real time control was applied, is shown in Fig.2. In this figure, half period (0.05s) of one scan is shown. In the phase of 3.758 ~ 3.774 seconds, the position of probe beam on the detector is kept on the center. However, before 3.758 and after 3.774 seconds, the position of probe beam and the voltage of detector side deflector, V_{def}, oscillated. In this phase, it was considered that the PI control became unstable[2]. A possible reason for this oscillation is that the probe beam may be blocked by the electrode of detector side deflector. In order to solve this problem, we will control the injector side deflector additionally to avoid blocking the probe beam.

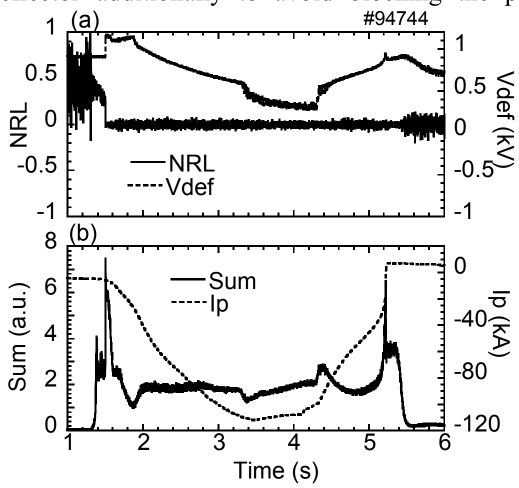

Fig. 1. (a) The temporal evolution of normalized horizontal position (NRL) and V_{def}, (b) The temporal evolution of the sum of detected current with the detector and I_p.

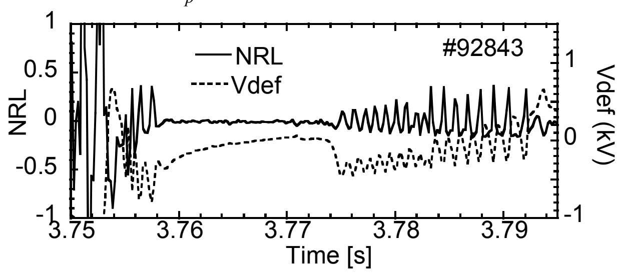

Fig. 2. The temporal evolution of normalized horizontal position (NRL) and V_{def} when real time control system was applied in profile measurement mode.

1) Nakamura, S., Shimizu, A., Ido, T. et al., submitted to Plasma Fusion Res.
2) Shimizu, A., Ido, T. et al. submitted to Rev. Sci. Instrum.